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United States
Department of
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Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Paper
INT-338

April 1985

Nutrient Release from Mount St. Helens Volcanic Ash and Retention by Western Montana Soil

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ACKNOWLEDGMENTS

The authors are grateful to Ron Barger and Roger Hungerford for assistance with this research. Financial support by the USDA Forest Service, Intermountain Forest and Range Experiment Station, is gratefully acknowledged.

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RESEARCH SUMMARY

Three soils of a wide fertility range, based on tree growth and soil chemistry, were covered by 0.4, 1, and 1.9 inches (1, 2.5, and 5 cm) of volcanic ash on the surface and leached for an equivalent of 3 years of rainfall (28.9 inches or 73 cm/year), along with an ashless control. The volcanic ash released a substantial amount of most biologically essential ions with the first leaching, but amounts released were lower with successive leachings. The three soils stored the most ions during the first leaching. Weathering of the ash did not appear to occur rapidly or result in acceleration of ion release. The least fertile soil retained the most ions, but there was no increase in conifer growth from the nutrients added through leaching of the volcanic ash. Soils with high calcium and magnesium levels lost some of these ions during leaching. The poorest soil showed some increase in calcium after treatment with ash and water. Sodium and potassium showed similar leaching and storage patterns. All soils lost potassium, but some small and insignificant increases in calcium were found after ash and water treatment. Phosphate was stored from only the heaviest ash application. Some of the original soil phosphate was lost, but heavier application of ash did result in slightly significant increases in available soil phosphorus. Nitrate losses tended to increase toward the end of the leaching trials. Increased nitrification could account for greater nitrate losses, but mineralization and nitrification did not fall within the scope of this study. The ash is capable of storing copper from incoming water but did not selectively remove other ions. For some soils, ion storage or loss was more easily explained than for others. These three soils with different pH, bulk density, and chemistry responded to the addition of low levels of ions differently. Some ions were stored more effectively when deeper ash layers were applied. Others tended to lose more ions with greater ash depth. The Coram soil (calcareous) did improve in lettuce production with 0.4 and 1 inch of ash added to the surface. The most fertile soil improved slightly in lettuce growth potential with the addition of ash on a short-term basis (3 months). Ash depths of over 1.9 inches may alter aeration and appear to reduce growth of both lettuce and conifers in the greenhouse.

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INTRODUCTION

The eruption of Mount St. Helens on May 18, 1980, left stages of chaos in the affected area. The devastation of the immediate impact area has created special ecological problems. The ashfall may be considered a natural fertilization or mulching process in less severely impacted areas such as western Montana. Could the 0.7 to 1.1 inches (2 to 3 cm) of ashfall in western Montana benefit tree growth?

The question is particularly important because of the possibility of future eruptions and fallout and the subsequent ecological effects.

Studies have shown changes in particle sizes in fallout with distance from Mount St. Helens (Ogren and others 1981; Chuan and others 1981; Farlow and others 1981; Danielson 1981). Studies on the chemical composition of the recent ashfall have shown variations in particle chemistry with distance from the volcano (Hobbs and others 1981; Inn and others 1981; Gandrud and Lazrus 1981; Vossler and others 1981). Ash is a potential natural fertilizer because it contains most of the ions needed for plant growth. Some ions are readily water soluble and available whereas others will be released after weathering.

In western Montana, soils with a wide range of natural fertility received about 0.78 inch (2 cm) of ashfall. This study examined the interaction of ions from the ash with three soils to determine if the addition of ash would significantly increase soil fertility to a level that might later reflect improved tree growth. Lack of water most often limits tree growth in western Montana, but on soils where nutrients are limited, the possibility exists that ashfall might improve future productivity. This may warrant special management practices such as using different spacing to increase the amount of root zone water and nutrients available to trees so that improved fertility could most favorably influence growth during the growing season. Ashfall could increase the available water retention in soils as well. The influence of ashfall on the physical aspects of soils was beyond the scope of this research, but with deep ashfall, considerable physical effects would be expected.

A previous study (Stark and Zuuring 1981) showed that adding one nutrient to soil in solution may result in predictable levels of storage or loss, or the loss of other ions. These relationships need to be examined with regard to volcanic ash and soils of varying fertility. Our research questions were:

1. What ion concentrations would be released from volcanic ash over prolonged leaching, equivalent to 3 years of rainfall?
2. How would three chemically and physically different soils store or lose ions with ion additions from ash and simulated precipitation?
3. What are the consequences of ashfall on forest soils relative to tree growth?

ASH AND SOIL COLLECTION SITES

Large quantities of local volcanic ash were not available. Therefore, unleached, fresh volcanic ash from Moses Lake, WA (contributed by Dr. Raymond Murray, geologist) was collected and homogenized in large plastic bags. Particle sizes for the ash were mostly 0.05 to 53 microns (Farlow and others 1981), which is similar to the size range at Missoula (0.16 to 53 microns).

One area from Lolo Pass, MT, has extremely poor granitic soils with a B horizon cation exchange capacity (CEC, Black 1965) of 3 to 4.2 meq/100 g and a moderate water-holding capacity determined by pressure plate extraction (11 percent, 1/3 minus 15 bars). The soils, from 4,600 ft (1 402 m) elevation, were removed from a depth of 15.7 inches (40 cm). These loamy skeletal soils belonging to the Selway Series are derived from the Idaho batholith and are Frigid Dystric Eutrocrepts. They are low in available ions, have an acid pH of 5.7 to 5.9, are overlain by 8 inches (20 cm) of andic cap, but are not droughty. The bulk density of the ash was 0.8 g/cc and that of the underlying soil ranged from 1.0 to 1.4 g/cc. Annual air temperatures range from −36 to 95 °F (−38 to 35 °C) with 42 inches (1 070 mm) of annual precipitation, mostly snow. Lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) is the area's main species, with radial growth averaging 55 rings/inch (22/cm). Ground vegetation is sparse.

The second soil collection site is the Coram Experimental Forest near Glacier Park in western Montana. The soils have some limestone inclusions and are moderately fertile with a pH of 7.9 to 8.1. Almost all conifer species of the region grow on these soils. Precipitation averages 31 inches (787 mm), mostly snow. Lack of water does not normally limit growth, at least in early summer. The soils are derived from argillite, impure limestone, and quartzite with some volcanic ash (Klages and others 1976). The bulk density of the mineral soil is 0.9 to 1.1 g/cc and the mean CEC in the B horizon is 13 meq/100 g. The soils are cryocrepts of the Felan series (andeptic Cryoboralfs or Eutroboralfs). Tree growth averages 11 rings/inch (4.4/cm) in the sampling area for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco, unmanaged stand). The ground vegetation is dense and vigorous with generally good growth. Annual air temperatures range from −24 to 93 °F (−31 to 34 °C). Sampling was at 3,986 ft (1 215 m) elevation.

The third site, a south slope in the Lubrecht Experimental Forest, is classed as a Typic Eutroboralf (Frigid). Annual air temperatures range from −40 to 105 °F (−40 to 40 °C), with 17.5 inches (447 mm) of precipitation, mostly snow (Steele 1981). The bulk density ranges from 1.3 to 1.6 g/cc. The site is at 4,019 ft (1 225 m) elevation and supports Douglas-fir, ponderosa pine (*Pinus ponderosa* Laws.), and western larch (*Larix occidentalis* Nutt.). Growth for pine averages 9 rings/inch (3.5/cm). The CEC of the B horizon is 21 meq/100 g of soil, and the pH ranges from 6.2 to 6.5. These are soils of moderate fertility, and lack of water limits growth, mainly in August.

EXPERIMENTAL PROCEDURES

Undisturbed soil cores could not be obtained in these rocky soils. Therefore, each lot of soil was homogenized separately to prepare a uniform medium for leaching. The soils, with separate bags of litter and duff, were collected from three areas. Topsoil (A horizon) and subsoil (B horizon) were kept separate and replaced in the cylinders in their natural sequence. Coarse fragments >0.4 inch (>1 cm) in diameter were removed, along with coarse organic debris. Forty PVC tubes 8 by 25.6 inches (20 by 65 cm) were filled with 20 inches (50 cm) of each soil type. To approximate the natural soil condition, each column contained 1.9 to 3.9 inches (5 to 10 cm) of A horizon on top with 15.7 to 17.7 inches (40 to 45 cm) of B horizon beneath. Uniform packing was used to reestablish something resembling the original soil density. The soil-filled cylinders were dropped on end onto a flat surface 10 times from 3.9 inches (10 cm) height to achieve uniform packing. The bottom of each tube was covered by clean muslin to act as a filter and retain the soil. Tube bottoms were set in large plastic pots fitted with Tygon tubing to act as a drain for leachate from the tubes. The tubes were set on leaching benches and litter and duff placed on the surface to the depth normal for each soil, 0.39 to 0.78 inch (1 to 2 cm) (fig. 1). Soil and litter volume equaled approximately 446 in^3 (7 308 cm^3). The 40 tubes of each soil were divided into four treatments of 10 tubes each. The treatments were: control—no ash added, 0.4 inch (1 cm) of ash added, 1 inch (2.5 cm) of ash added, and 1.9 inches (5 cm) of ash added over a 20.5-in^2 (133-cm^2) surface area. The volumes of ash added to the soil were 8.1 in^3 (133 cm^3) for the 0.4-inch depth of ash, 20.5 in^3 (337 cm^3) for 1-inch depth, and 40.5 in^3 (633 cm^3) for the 1.9-inch depth. Chemical characterization of the soils appears in table 1.

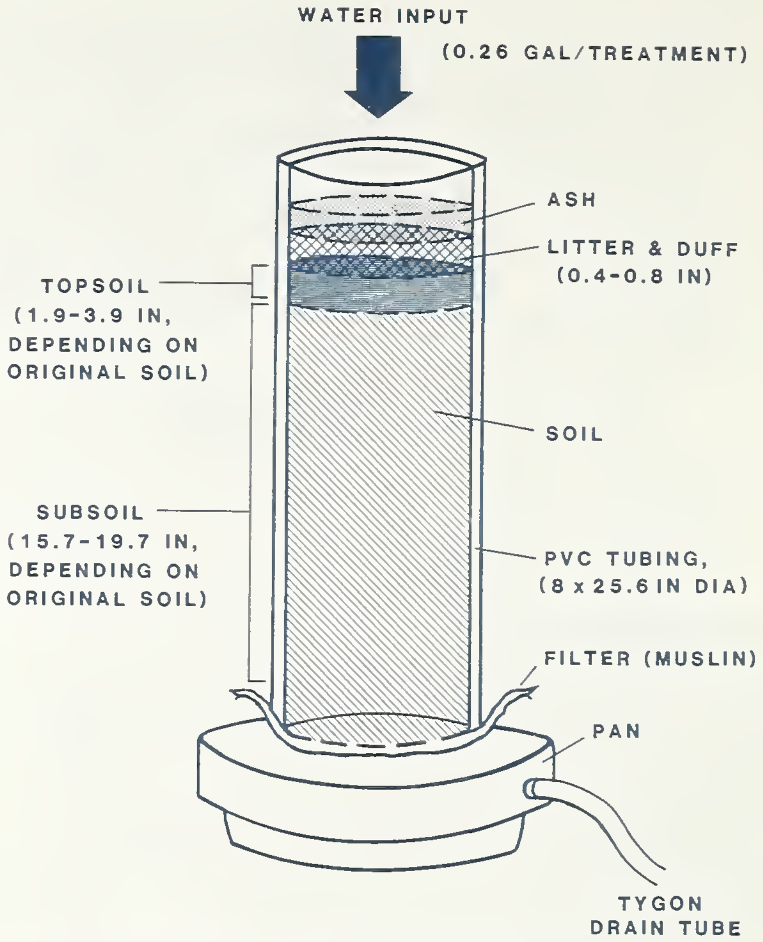
WATER INPUT
(0.26 GAL/TREATMENT)
ASH
LITTER & DUFF (0.4-0.8 IN)
TOPSOIL (1.9-3.9 IN, DEPENDING ON ORIGINAL SOIL)
SOIL
SUBSOIL (15.7-19.7 IN, DEPENDING ON ORIGINAL SOIL)
PVC TUBING, (8 x 25.6 IN DIA)
FILTER (MUSLIN)
PAN
TYGON DRAIN TUBE

Figure 1.—Diagram of leaching apparatus. Forty such tubes were used with each soil, totaling 120 tubes set in drainage racks.

One liter of water (2.9 inches or 7.3 cm depth in the cylinders) was applied to each cylinder once a week for the first 10 weeks and every other week thereafter from November 18, 1980, to November 2, 1981, for a total of 30 leachings. All tubes were initially saturated and the first leaching completed and analyzed chemically before the ash was applied. The first week (0) represents leaching before ash was added to the surface. A total of 86.6 inches (220 cm) depth. 7.3 cm/treatment of water was applied to each cylinder, the equivalent of 3 years of precipitation as a mean for the three sites (28.9 inches or 73 cm/year). Air temperatures during leaching remained above freezing, but ranged with the seasons from 34 to 86 °F (1 to 30 °C).

Greenhouse leaching tests of this type cannot be expected to create leaching conditions or tensions in the soil column that are identical to field conditions. Therefore, results cannot be extrapolated to field situations without reservations. This study could not have been conducted in the field with the appropriate ash depths. The work is intended to explore trends in leaching losses from three soils if they did receive ashfalls of the three depths.

Large quantities of distilled water were not available for this study. Because the local tap water approximates the ion content quality of natural rain water (table 2),

Table 1.—Mean and standard deviation for the ion content of the 1N ammonium acetate soil extracts as μg/g before and after an equivalent of 3 years of leaching with no ash and 0.4, 1, and 1.9 inches of ash on the litter surface, as ppm, and as meq/100g for original soil before leaching

Soil and element	After leaching (B horizon)								Before leaching[1,2] (B horizon)		
	No ash		0.4 inch		1 inch		1.9 inches				
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	meq/100g
	ppm										
Lolo											
Ca	601	22	596	31	589	44	596	37	407	97	2
Fe	.9	.14	1.2	1.1	1.0	.2	105	10	1.2	1.9	.006
K	101	5.8	110	5.9	105	4.5	105	6.4	146	37	.37
Mg	106	3.3	103	4.2	101	2.7	108	5.2	90	18	.7
Mn	2.3	.7	2.6	.5	2.3	.4	2.3	.6	2.2	.28	.01
Na	47	10.4	61	19.5	34	5.6	37	5.9	46	8	.2
Si	113	17.7	96	36	52	23	647	17.0	—	—	—
Zn	.4	.1	.3	.2	.2	.05	.4	.06	.3	.3	.0009
Cu	.1	0	.1	0	.1	0	.1	0	.1	0	0
									Calculated base sat. = 78%		
Coram											
Ca	8,259	39	8,323	47	8,474	57	8,526	44	8,000	2,100	40
Fe	1.0	.3	.9	.05	1.0	.09	1.0	.3	1.4	1.0	.007
K	286	6.6	280	4.0	274	8.9	275	6.5	260	80	.66
Mg	282	5.3	280	3.3	276	4.2	276	4.5	269	124	1.0
Mn	4.5	1.1	4.5	1.1	5.1	.8	4.3	.6	2.3	.9	.01
Na	41	12.4	46	13.7	44	13.6	54	15.1	42	10	.04
Si	144	29.7	125	41.9	157	84.8	202	54.6	—	—	—
Zn	.15	.1	.20	.1	.24	.1	.12	.09	1.0	.4	.001
Cu	.2	0	.2	0	.2	0	.2	0	.2	0	0
									Calculated base sat. = >320%[3]		
Lubrecht											
Ca	3,460	63	3,505	52	3,470	40	3,520	94	3,568	90	17.8
Fe	.9	.2	.9	.1	.9	.1	1.1	.1	.6	.2	.003
K	1,158	16.9	1,172	18.1	1,153	17.0	1,187	9.5	1,160	70	2.9
Mg	494	6.0	491	10.2	478	6.1	476	10.4	480	10	3.9
Mn	1.4	.5	1.5	.5	1.7	.3	1.9	.3	1.2	.9	.006
Na	87	6.4	88	4.4	94	4.6	101	4.6	56	30	.24
Si	264	54	268	50	284	54	289	57	—	—	—
Zn	.1	.03	.08	.02	.09	.03	.16	.09	1.0	.2	.003
Cu	.1	0	.1	0	.15	0	.1	0	.12	0	0
									Calculated base sat. = 118%[3]		

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[1] Depth 8 to 12 inches (20 to 30 cm).

[2] "Before leaching" figures are taken as small subsamples from the area studied and are not necessarily comparable to the actual soils used; they will not reflect before and after chemical conditions of the same soil column. The "before" leaching data represent the natural variations of soils while the "after," "no ash" control represents the results from homogenized soil samples.

[3] The 320 percent base saturation recorded for the Coram soil and the 118 percent for the Lubrecht soil are artifacts of the soil extraction procedure. Ammonium acetate (1N) will remove soluble Ca and exchangeable Ca resulting in erroneously high extractable Ca data. These soils are thought to be normally <50 percent base saturated.

Table 2.—Range of ion levels found in western Montana precipitation and tap water

Source	Ca	Cu	K	Mg	Na	NO_3
	ppm					
Precipitation[1]						
Low	0.3	0.05	0.02	0.01	0.04	0.9
High	5.6	.04	.32	.06	.05	2.2
Tap water						
Low	2.2	1.2	2.8	7.0	7.1	1.0
High	45.4	6.8	3.5	15.5	11.5	2.2

---

[1] Note that most forest soils receive throughfall that often has up to 10 times higher ion concentrations than occur in precipitation.

tap water was used to simulate the influence of natural precipitation. This made it possible to study the influence of ion interactions natural to rain water that would not occur in measurable amounts in distilled water. If the exchange sites were saturated with divalent ions, elevated levels of calcium in the tap water would show up in the leachate. If many exchange sites were occupied by monovalent H+, the calcium ions would be stored. Failure of soils to store ions when the exchange sites were or were not saturated could be examined using tap water but would not have been possible with distilled water. Large fluctuations in tap water quality occurred only twice during the study, following major storms (weeks 5 and 16). The water used was analyzed for all 11 ions studied with each leaching to approximate the atmospheric ion inputs.

The leachate collected from each cylinder was subsampled the day following application and, using atomic absorption spectroscopy, analyzed for calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), and zinc (Zn). Phosphate was determined colorimetrically using the ammonium molybdate-stannous chloride method (APHA 1971). Phosphate levels were often below the detection limit (<0.05 ppm) and complicated by the varying turbidity of the samples. Nitrate and pH were determined by specific ion analyzer (EPA 1974). The levels of iron, manganese, zinc, and phosphate stored were so low that these ions are excluded from discussion in this paper.

Equivalent volumes of ash were leached with water for 30 weeks, and for each treatment the leachate was analyzed to determine the levels of ions coming out of the ash and entering the soil. Input of ions from ash was added to the input from the tap water. Net weekly ion loss from the soil or gain to the soil was plotted. The study was not designed to establish complete ionic balances for these soils.

After leaching of the soils was concluded, two successive crops of Simpson's black-seeded lettuce were planted in each tube, watered regularly, and harvested at maturity for short-term bioassay (dry weight). The dry weights of lettuce were used to judge if the soils had improved in fertility after an equivalent of 3 years of leaching with three depths of volcanic ash on the surface. Lettuce dry weights and foliar nutrient content were compared using t-tests to those of the controls (no ash added but leached 30 weeks with tap water).

Four species of conifers—lodgepole pine, ponderosa pine, western larch, and Douglas-fir—were grown in tubes with ash in a greenhouse to test the longer term influence of ash on tree seedling growth. Small tubes were filled with either Lubrecht or Lolo soil (no Coram soil was available), and 0, 0.4 inch (1 cm), 1 inch (2.5 cm), or 1.9 inches (5 cm) of ash was added to the surface. Soil samples were from 7.8 to 15.7 inches (20 to 40 cm) depth. Pregerminated seeds of each species were added to the top and watered. Seedling heights were measured for each soil and ash depth and the t-test was used to determine if height differences were significant. Seedling heights were measured at the end of the first and second growing seasons, and seedling condition was recorded as good, fair, or poor depending on color, growth, and the development of new needles. Only water was added every 2 days during the growing season.

Subsamples of soil from each of the 120 tubes were analyzed after a year of leaching to determine whether the loss or gain of ions to the soil would show up as differences in 1N ammonium acetate extractable ions available to these plants, or if they had been complexed in less available form. These extracts were analyzed using an inductively coupled plasma spectrometer for 16 ions (table 1). This instrument was acquired after the column leachings began and therefore was not used for leachate analysis.

STATISTICAL TESTS OF LEACHATE AND SOILS

The concentrations of Ca, Cu, H, K, Mg, Na, and NO_3 in soil leachate and ammonium acetate extracts of each soil after leaching were tested using analysis of variance. Data for each soil were treated separately to compare the ion concentrations in leachate and soil extracts under each ash depth, including a control. The ANOVA table:

Source	df	MS	F
Trt	3	MS_{trt}	$F=\frac{MS_{trt}}{MS_{error}}$
Error	36	MS_{error}	
Total	39		

Data were not compared statistically between soil types because of obvious differences in chemistry. The leachate data were summed for the entire period of the tests to estimate net ion storage or loss. In testing for homogeneity of variances, each ion had to qualify at the 0.05 level for two of three tests (Cochran's C, Bartlett-Box F, and Hartley's). The homogeneity of variance was rejected if an ion failed more than one of these tests.

All ions from soil and leachate that showed homogeneous variances are included. Ion concentrations were then tested at the 0.05 significance level with Duncan's MRT and Fischer LSD methods of multiple comparisons. The LSD results for each ion from leachate or soil were used only if they differed from the Duncan test and if group sizes were unequal. This was the case only for Coram calcium summed net leachate data.

Weekly ion loss or gain to each soil was also plotted to show trends with time. Seedling height growth was tested using t-tests and analysis of variance.

RESULTS FOR SEVEN IONS

The following are research results on ion additions and ion loss or storage by soil for selected ions. Ion release is addressed first for each ion, then ion loss or storage from soil is discussed.

Hydrogen

The ash released hydrogen for 2 weeks and then assumed a steady but low release of H+ (figs. 2A,B).

Hydrogen ion levels in the leachate from Lolo soils tended to be relatively uniform over the period of the tests (figs. 2A,B). The major fluctuation at week 1 for the 1.9-inch (5-cm) ash treatment shows that the soils took up the hydrogen ions added from the ash. Storage did not persist beyond the first week, nor was it followed by a peak ion loss. Differences between treatments were small. Hydrogen ion storage and loss was almost identical for all three soils tested.

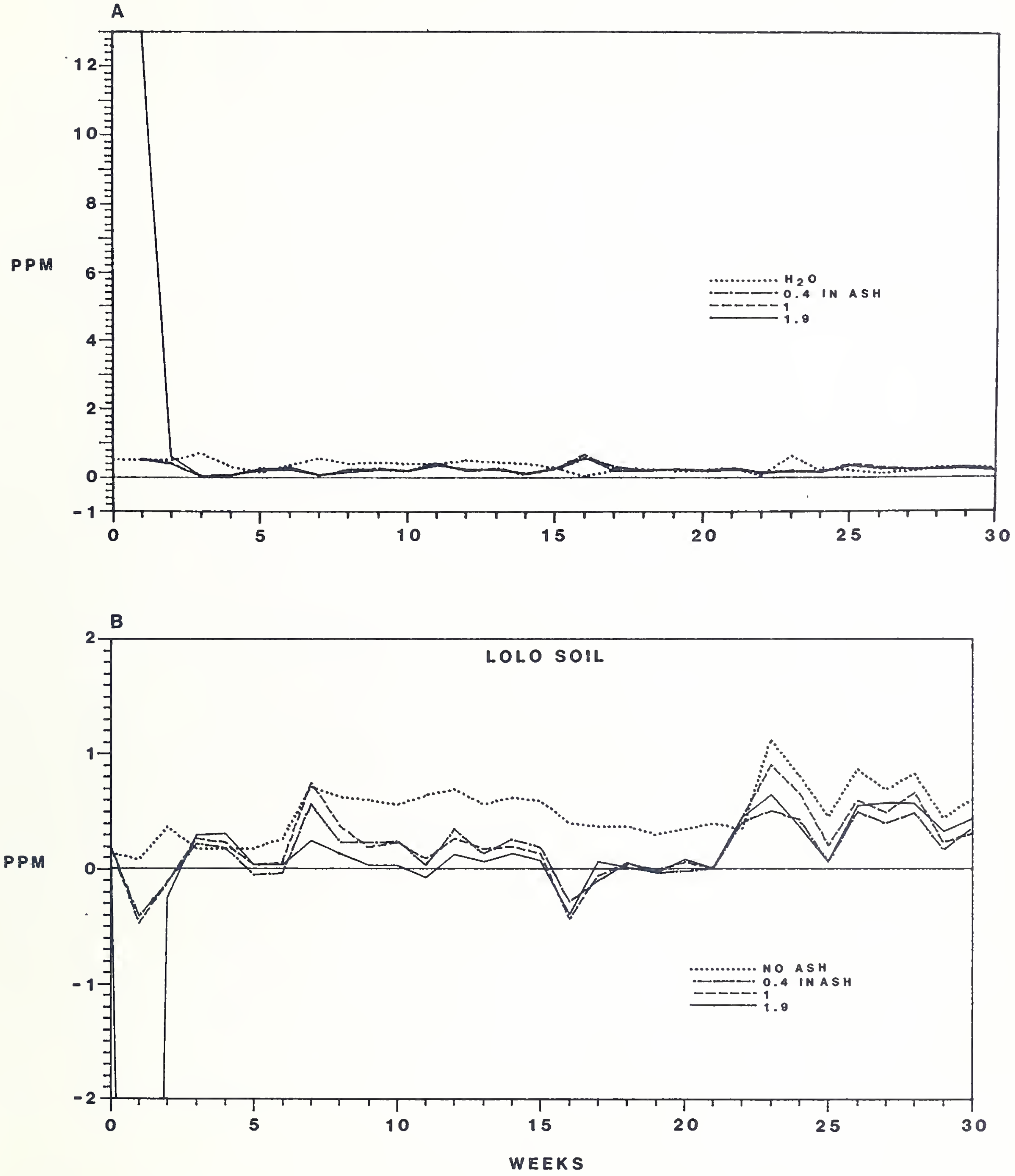

Figure 2.—Input (A) and loss or storage (B) of hydrogen as ppm × 10^{-4} for Lolo Pass soil. The pattern from other soils was identical to that from Lolo.

Calcium

Calcium release from the ash was high for the first 5 weeks for all treatments. High levels of calcium were added by the water on the 5th and 16th weeks from storms. Otherwise, the ash and water added low amounts of calcium after the first 5 weeks (fig. 3A).

Calcium storage and loss patterns were similar for all three soils. The Lubrecht soil was intermediate in storage and loss. The Coram soil showed variability in calcium release over time. Lolo soils stored over 40 ppm Ca when it was available. This shows that the exchange sites were not saturated and small additions of calcium from water (or rain water) are easily stored. The Lolo soil, which was originally low in Ca (407 μg/g, table 1, fig. 3B), had greater net Ca storage than either of the other soils, with only minor calcium losses (6 μg/g maximum for any treatment). This soil has a low base saturation, allowing Ca storage. The Coram soils that initially had 8 259 μg Ca/g compared to 407 μg Ca/g of Lolo soil, lost Ca throughout the study regardless of treatment (table 1, fig. 3C). The Coram soils lost Ca consistently after the third week of leaching. The ammonium acetate extractant used removed more calcium than was actually on the exchange sites for the Coram and Lubrecht soils, resulting in data that showed over 100 percent base saturation (figs. 3B,C, table 1). Even the control soil lost Ca, indicating that initially there were considerable amounts of water-soluble calcium in the soil. This soil appears to be able to control Ca losses with prolonged leaching because fluctuations in loss were lower and more steady after week 16. Lubrecht soils (fig. 3D) stored Ca initially (week 1) and during heavy runoff (weeks 5 and 16), which produced high Ca (46-48 ppm) in the tap water. This occurred in spite of the fact that the soil extraction (table 1) showed the soil exchange sites to be already saturated. Obviously, the extraction of soil with 1N ammonium acetate is not dependable for some soils. Note the differences that were needed in scale to accommodate large differences in soil chemistry. The extraction energies of water and ammonium acetate are commonly hypothesized to be different (Black 1965), yet the ammonium acetate method is the main one acceptable for soils.

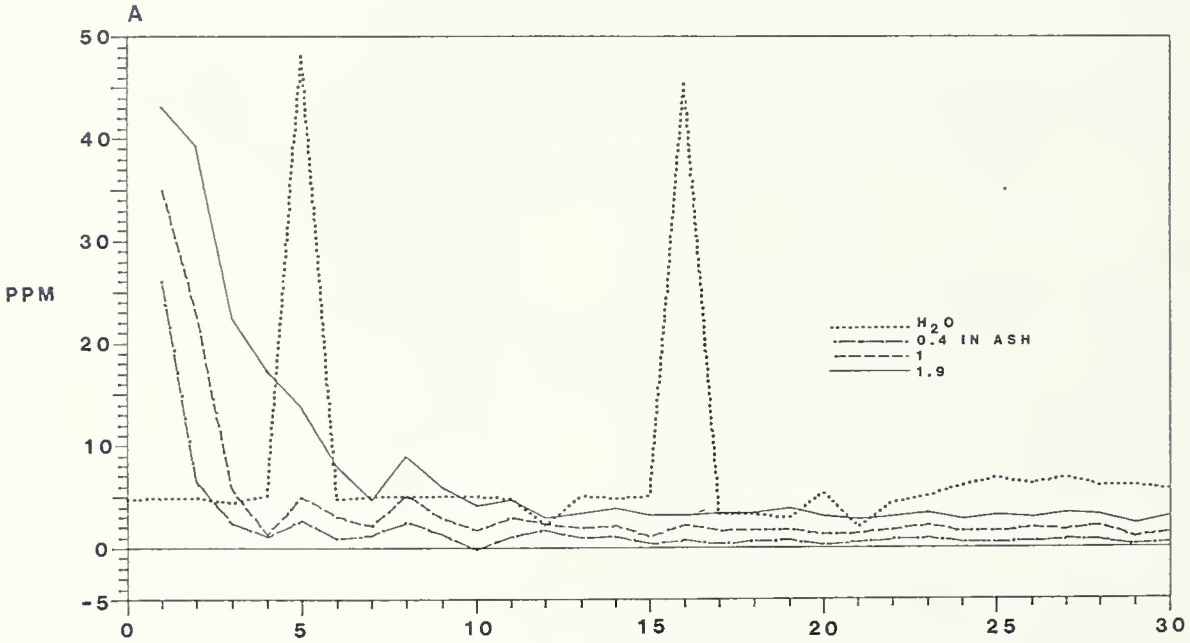

Figure 3.—Input of calcium from water and ash (A) and storage (−) and/or loss (+) of calcium for Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

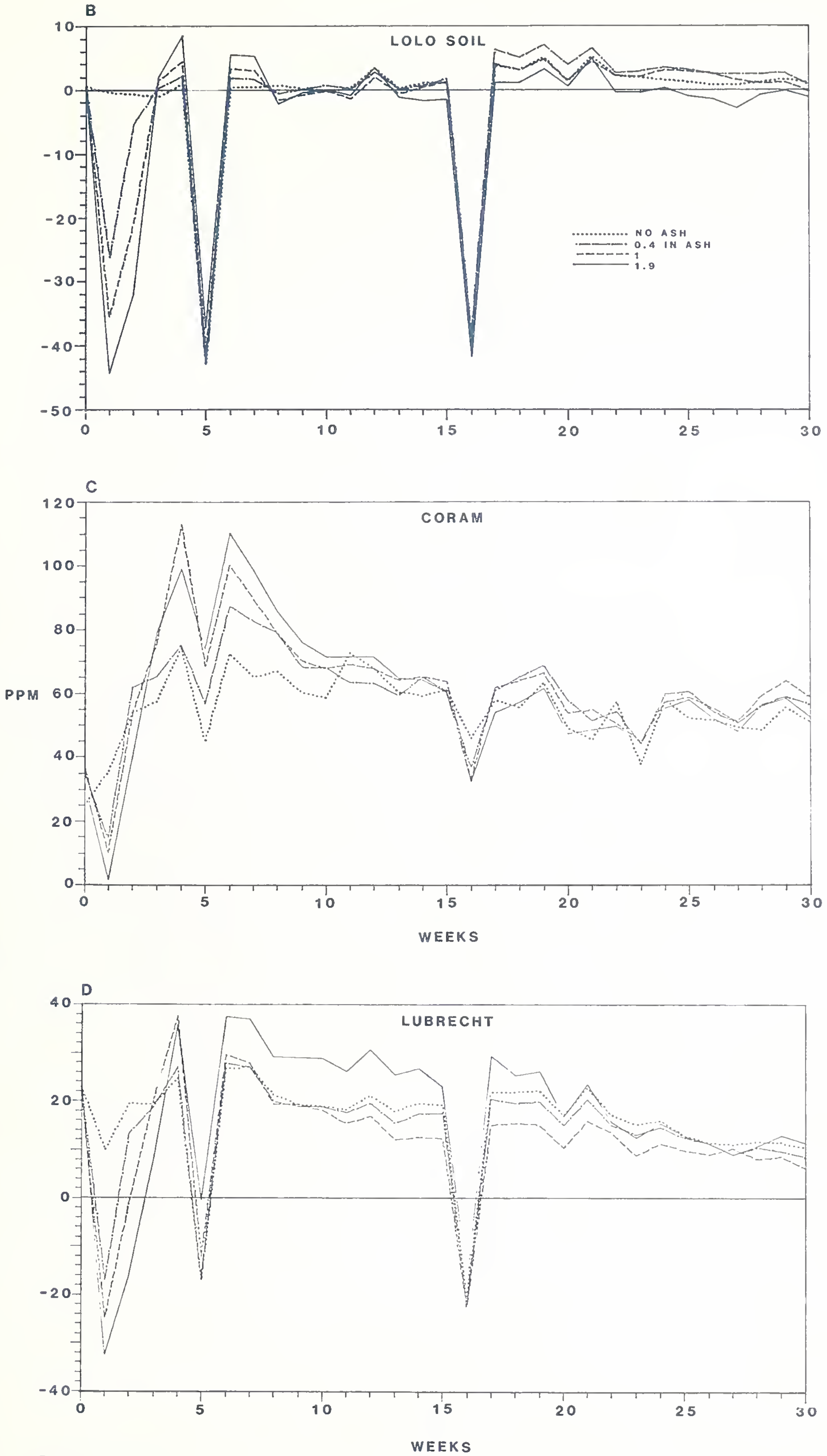
B
LOLO SOIL
10
0
-10
-20
-30
-40
-50
0
5
10
15
20
25
30
NO ASH
0.4 IN ASH
1
1.9
C
CORAM
120
100
80
PPM
60
40
20
0
0
5
10
15
20
25
30
WEEKS
D
LUBRECHT
40
20
0
-20
-40
0
5
10
15
20
25
30
WEEKS

Figure 3.—(Con.)

Copper

Copper leached from the ash for the first 4 weeks, but loss then declined to low levels (fig. 4A). Tap water normally has high levels of Cu.

Copper storage and loss were almost identical between Lubrecht, Coram, and Lolo soils (figs. 4B,C,D). Net leachate often showed storage of Cu by ash-treated soils, but the ash actually removed Cu from the tap water. This made it appear that the soil was storing Cu when in fact the ash was storing the Cu. Actual soil storage would occur only when the water input of copper exceeded the storage capacity of the ash. The levels of Cu were low but above the detection limits. Perhaps this ash-stored Cu will be released to the soil in the future. The storage capabilities of ash for copper would not have been detected with distilled water. Ammonium acetate extraction removed only low levels of Cu (0.1 to 0.2 ppm) from any of the three soils (table 1).

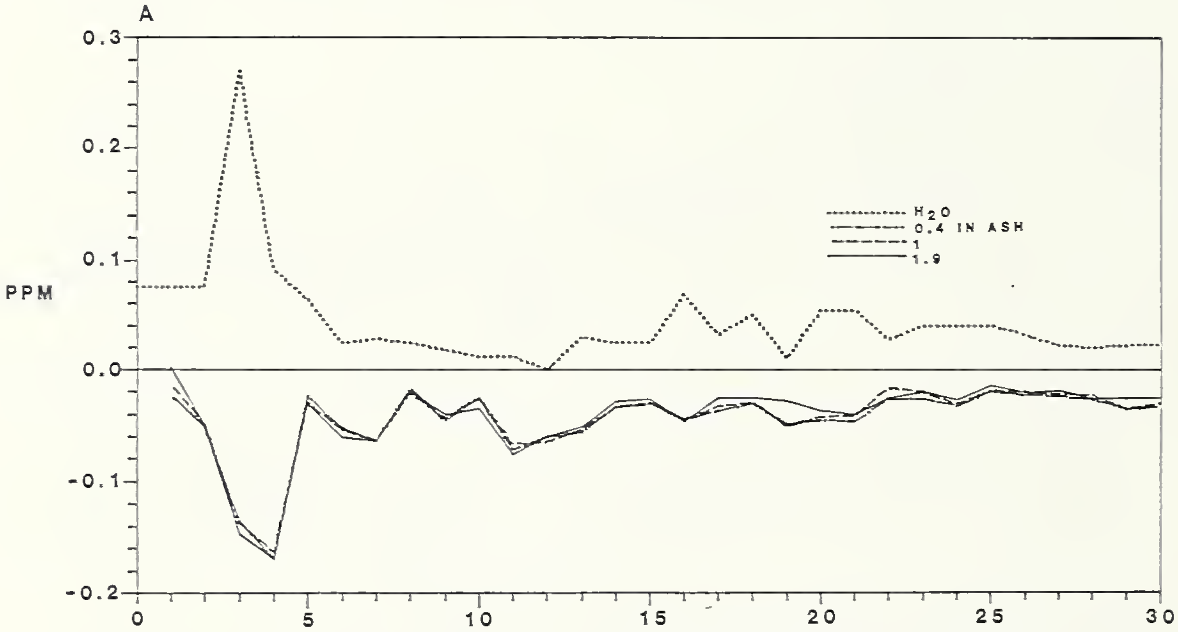

Figure 4.—Input of copper from water and ash (A) and storage (—) and/or loss (+) of copper from Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

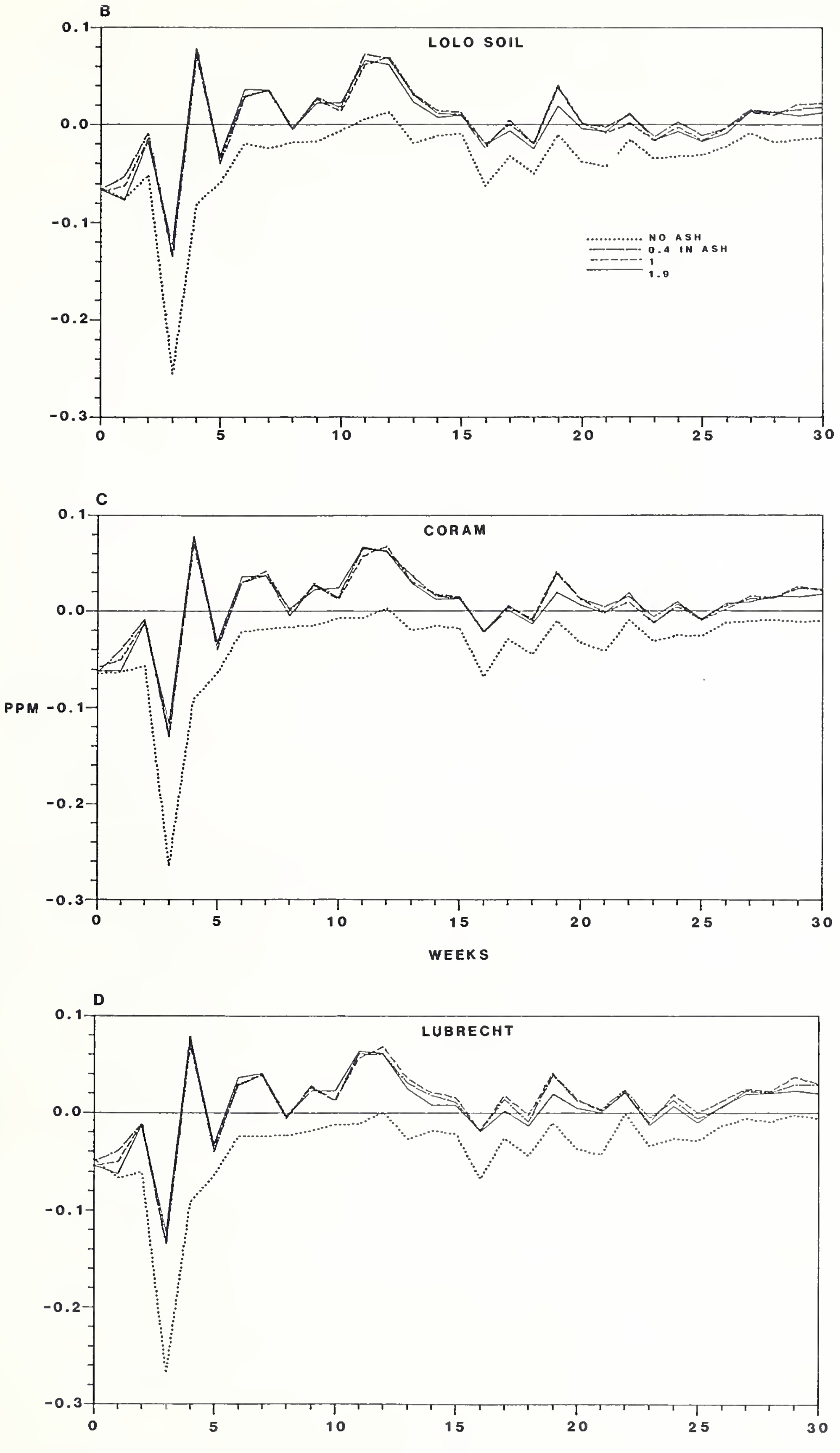
B
LOLO SOIL
0.1
0.0
-0.1
-0.2
-0.3
0
5
10
15
20
25
30
NO ASH
0.4 IN ASH
1
1.9
C
CORAM
PPM
WEEKS
D
LUBRECHT
WEEKS

Figure 4.—(Con.)

Potassium

The highest levels of K were released from ash during the first three leachings. Losses from ash thereafter were low and regular (fig. 5A).

All three soils showed similar behavior with K added from ash (figs. 5B,C,D). After the initial peak of K input from the ash treatments, no K storage occurred in any of the three soils. The magnitude of net K loss from these soils is surprising and unexplained. The storage of calcium by the Lolo soil and the base saturation data (table 1) suggest that the exchange sites are not saturated in the Lolo soil so that ion storage should be possible. The base saturation of the Lubrecht and Coram soils is misleading because of the extracting agent normally used with soil. The authors suspect that the soils were not base saturated initially, but the exchange sites were flooded with calcium solubilized by the extracting solution. However, potassium is monovalent and has a relatively weak affinity for cation exchange sites, making it especially mobile and susceptible to leaching loss in the presence of excess divalent calcium.

Coram soils showed low storage of K (0.4 ppm) during the first week after losses from the pretreatment leaching (fig. 5C). Net losses of K from soil are of concern because this ion is often scarce.

Potassium losses from Lolo soils followed the pattern for H and Na (see figs. 2B and 7B)—the more ash applied, the more K stored during the first week. After week 1, net losses of K occurred from all Lolo treatments, with greatest losses from the controls. The soils may have been unable to store more K because of K or Ca saturation, or K may be poorly held by these soils. The activation energy of water for Ca is high, supporting the second explanation.

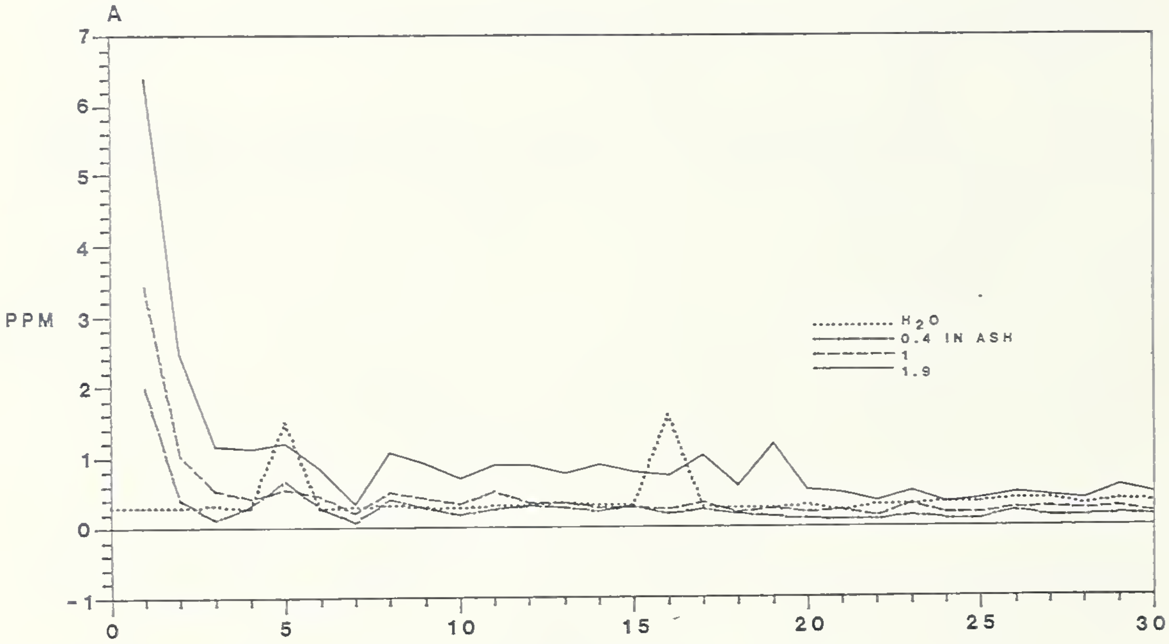

Figure 5.—Input of potassium from water and ash (A) and storage (—) and/or loss (+) of potassium from Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

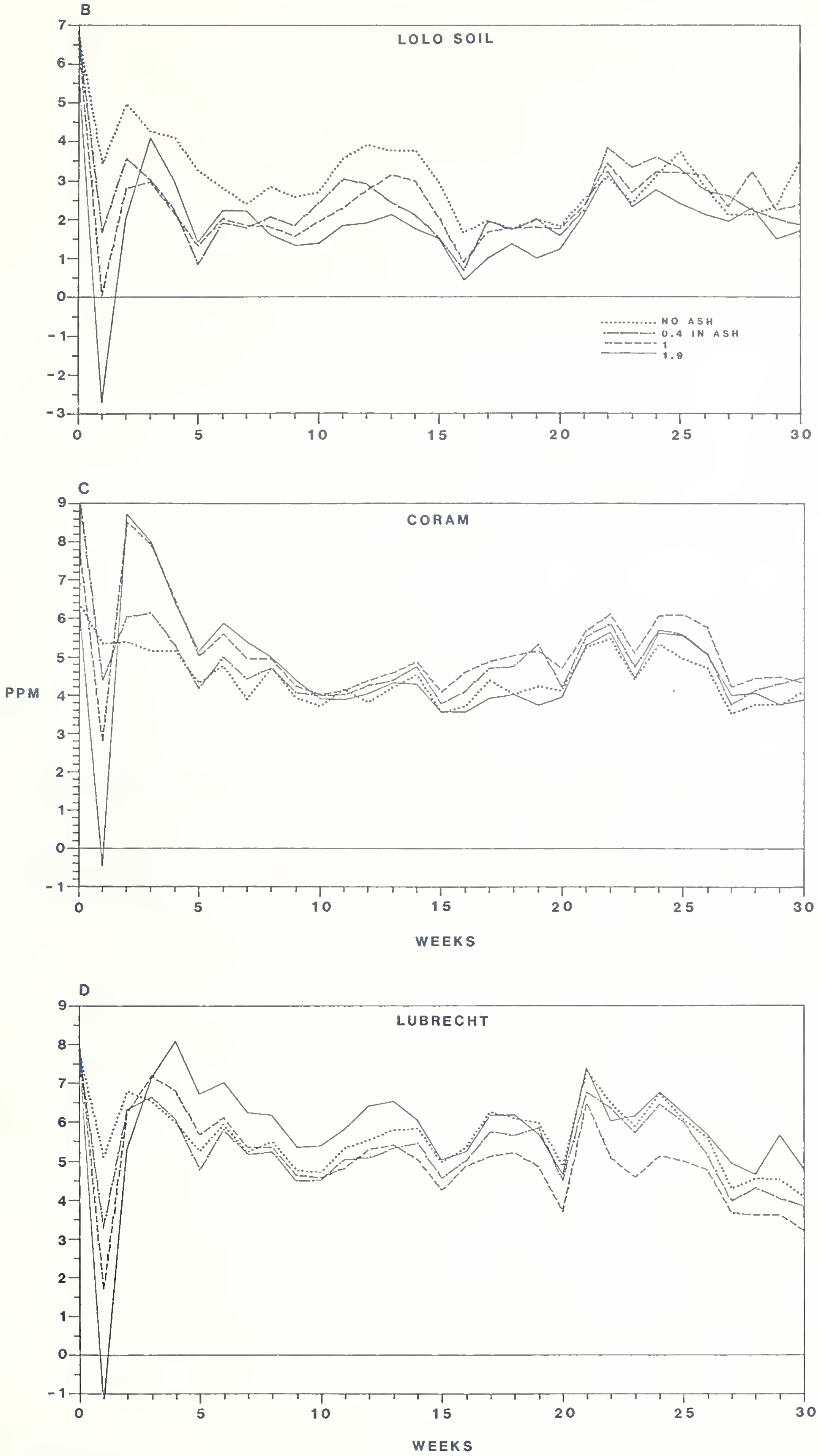
B
LOLO SOIL
7
6
5
4
3
2
1
0
-1
-2
-3
0
5
10
15
20
25
30
NO ASH
0.4 IN ASH
1
1.9
C
CORAM
PPM
9
8
7
6
5
4
3
2
1
0
-1
0
5
10
15
20
25
30
WEEKS
D
LUBRECHT
9
8
7
6
5
4
3
2
1
0
-1
0
5
10
15
20
25
30
WEEKS

Figure 5.—(Con.)

Magnesium

All ash treatments released the most magnesium during the first 3 weeks of leaching (fig. 6A).

Magnesium followed a pattern of fluctuation similar to that of calcium but with the actual concentrations lower, as expected. Magnesium inputs from water in weeks 5 and 16 resulted in magnesium storage by all three soils in those weeks. The Lolo soil showed little loss of Mg but the greatest storage (figs. 6B,C,D). This soil was the lowest in Mg (90 μg/g, table 1). Lubrecht soils were again intermediate. Coram soils, initially high in Mg, stored no Mg after the first week of leaching (fig. 6C,D). High Mg inputs at weeks 5 and 16 resulted in the same storage or reduction in loss as seen with Ca and should be interpreted likewise.

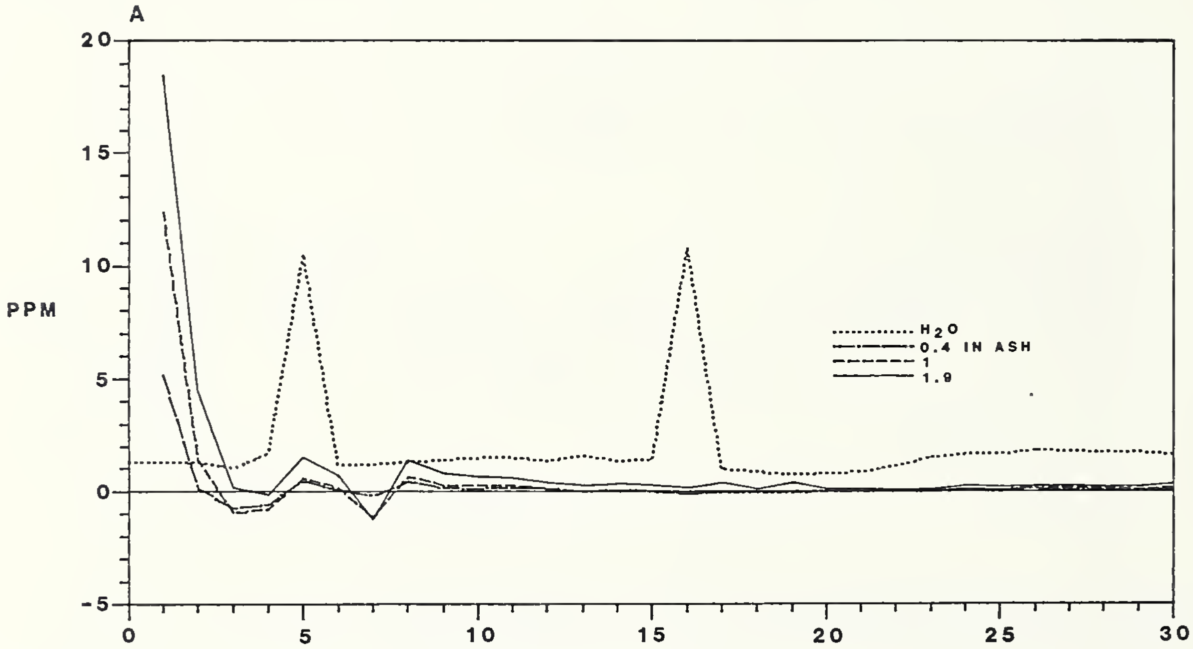

Figure 6.—Input of magnesium from water and ash (A) and storage (−) and/or loss (+) of magnesium from Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

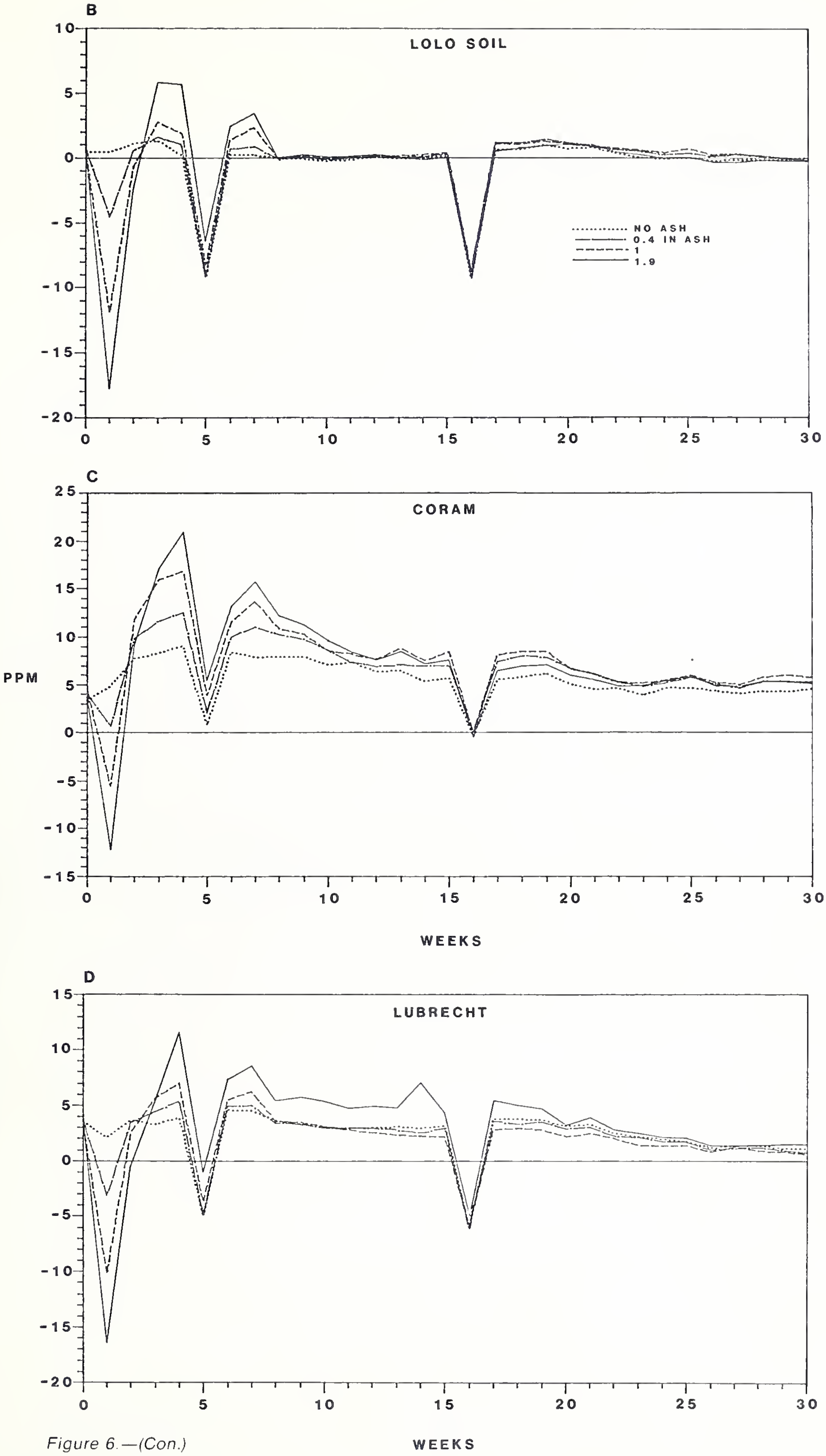
B
LOLO SOIL
10
5
0
-5
-10
-15
-20
NO ASH
0.4 IN ASH
1
1.9
C
CORAM
25
20
15
10
5
0
-5
-10
-15
PPM
WEEKS
D
LUBRECHT
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30
WEEKS

Figure 6.—(Con.)

Sodium

The ash released the highest levels of sodium during the first 4 weeks of leaching, with steady, low releases throughout the rest of the study (fig. 7A).

Sodium losses were almost identical for all three soils (figs. 7B,C,D). This highly mobile ion was originally present in the three soils in similar concentration (42 to 58 µg/g) and so was expected to leach similarly under nearly identical leaching forces. The loss of Na from the ash and its storage by the soils during the first week was almost directly proportional to the Na in the ash. The controls stored almost no Na. With ash treatment all soils showed a short period of Na storage with low and almost steady loss thereafter. High Na storage by the nutrient-poor Lolo soil, to 110 µg/g for the 1.9-inch (5-cm) ash treatment, may have adversely affected the storage of other ions for this low exchange capacity soil.

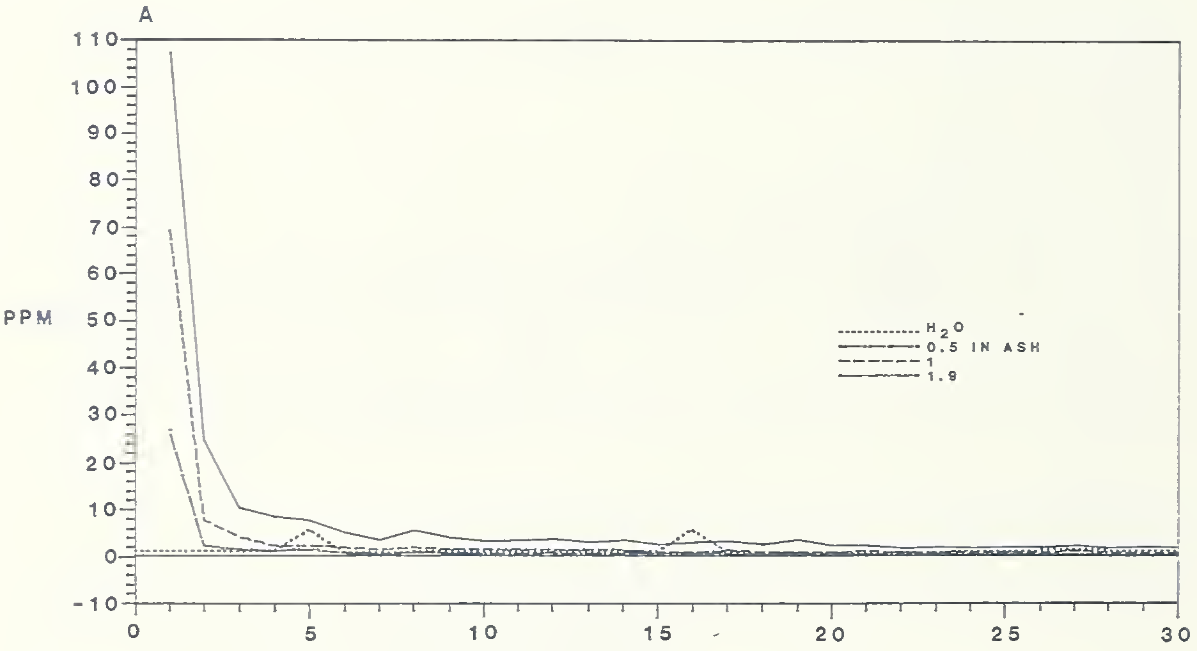

Figure 7.—Input of sodium from water and ash (A) and storage (−) and/or loss (+) of sodium from Lolo (B), Coram (C) and Lubrecht (D) soils as ppm.

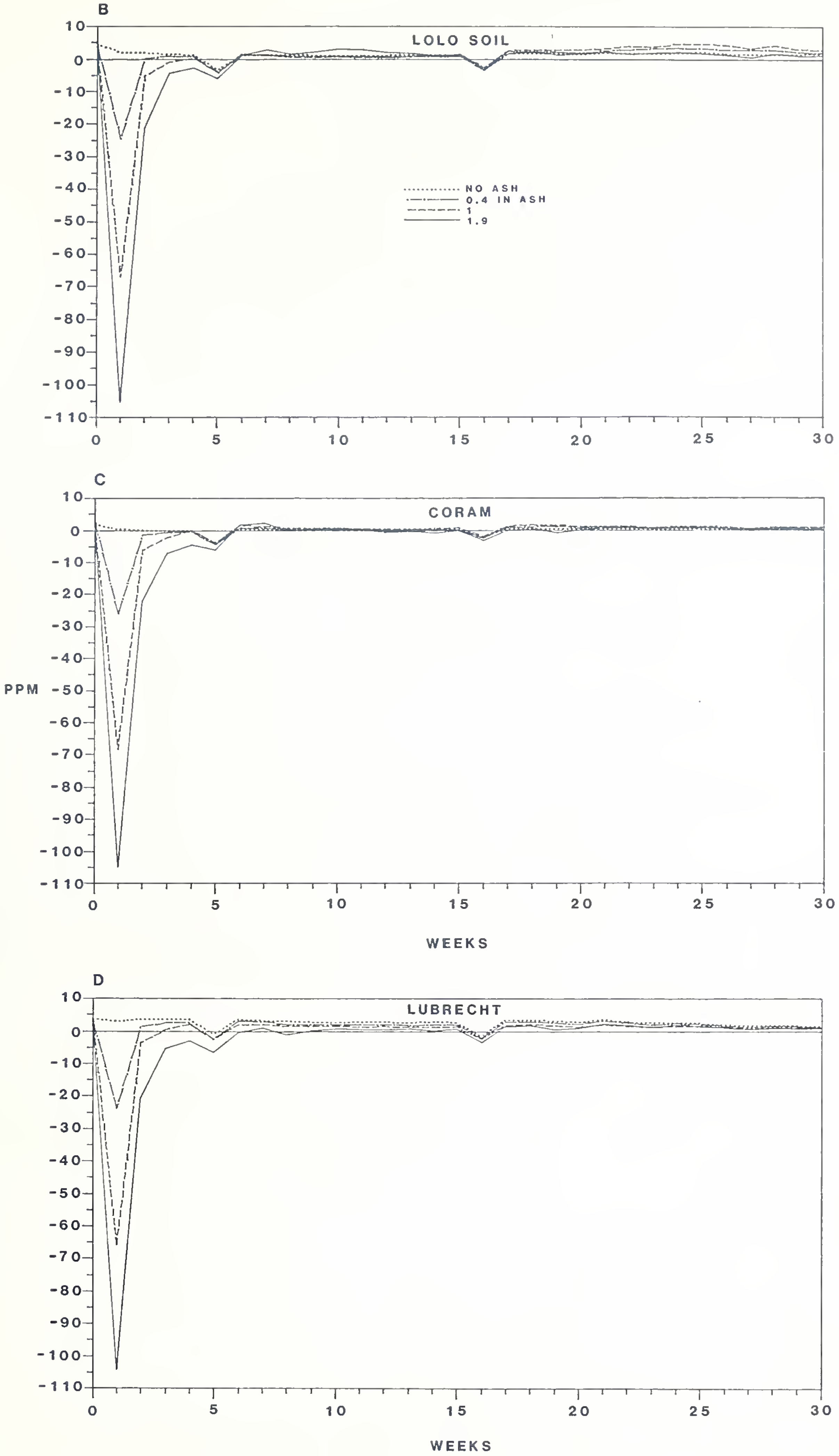
B
LOLO SOIL
NO ASH
0.4 IN ASH
1
1.9
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
0
5
10
15
20
25
30
C
CORAM
PPM
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
0
5
10
15
20
25
30
WEEKS
D
LUBRECHT
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
0
5
10
15
20
25
30
WEEKS

Figure 7.—(Con.)

Nitrate

Nitrate levels in the water varied considerably during the study, and nitrate release from ash was quite variable (fig. 8A).

Nitrate loss and retention for Lubrecht soils most closely resembled that of the Coram soils except that Lubrecht had initially high NO_3 (47 ppm). Both showed an accelerated loss near the end of the leaching cycle when soil temperatures were warmer (figs. 8B,C,D). Increased losses of NO_3 may be a reflection of increased nitrification or saturation of the anion exchange sites. Nitrate storage was generally low (12 ppm), the overriding pattern being one of NO_3 loss. Lolo soils lost and gained small amounts of NO_3 for the first 19 weeks (fig. 8B). As with the other soils, considerable NO_3 losses occurred from week 20 on.

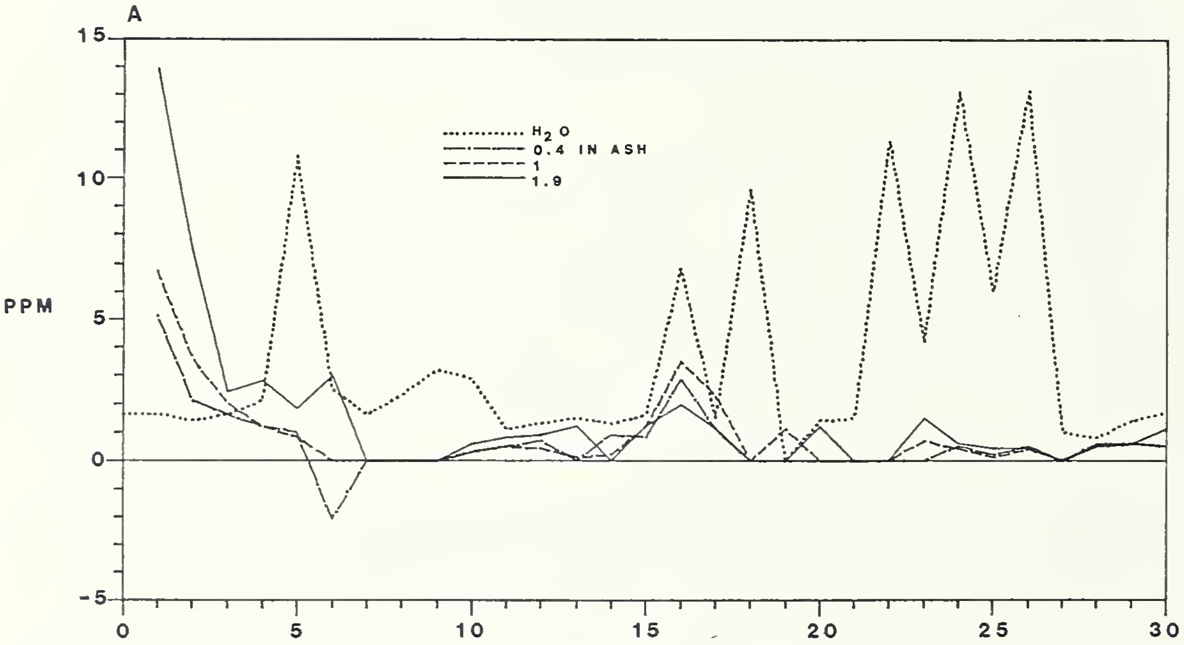

Figure 8.—Input of nitrate from water and ash (A) and storage (−) and/or loss (+) of nitrate from Lolo (B), Coram (C), and Lubrecht (D) soils as ppm.

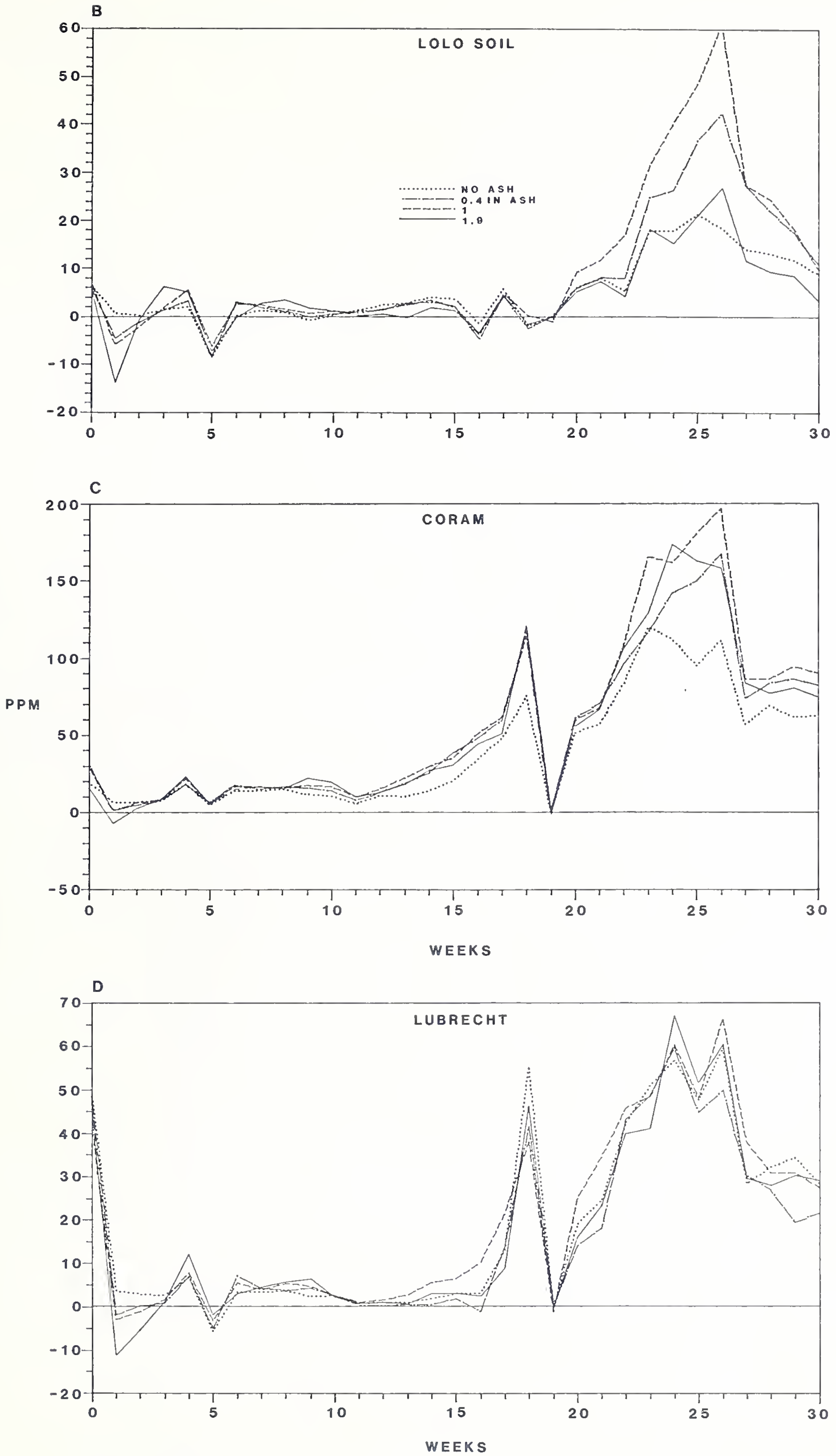
B
LOLO SOIL
NO ASH
0.4 IN ASH
1
1.9
60
50
40
30
20
10
0
-10
-20
0
5
10
15
20
25
30
C
CORAM
200
150
100
50
0
-50
PPM
0
5
10
15
20
25
30
WEEKS
D
LUBRECHT
70
60
50
40
30
20
10
0
-10
-20
0
5
10
15
20
25
30
WEEKS

Figure 8.—(Con.)

RESULTS BY SOIL TYPE

The following are research results on ion additions and loss by each of the three soils used in this study.

Lolo Soil (Dystric Eutrocrept)

This soil leached over 30 weeks lost Cu at the 0.4- to 1.9-inch (1- to 5-cm) ash depths, K and NO_3 at all ash depths (table 3). The control lost Na. Magnesium was stored by the Lolo soils, but calcium was lost only with the 0.4-inch depth of ash for all depths of ash applied. Potassium losses were significantly different between the 1- and 1.9-inch (2.5- and 5-cm) ash treatments (table 3). All treatments produced significantly different sodium and hydrogen levels in the leachate from this soil. Nitrate losses were higher in the 1-inch ash treatment, compared to the control and 0.4- and 1.9-inch treatments.

This nitrate-deficient soil failed to store any anions, suggesting a deficiency in anion exchange capacity. It tended to store other ions such as Ca and Mg that were initially low in the soil. Another study (Stark and others 1984) showed this soil to be severely nitrogen deficient. Ions added from ashfall would be unlikely to improve growth unless nitrate was added and retained.

Coram Soil (Cryocrept)

Calcium, copper, potassium, magnesium, and nitrate were lost from this soil as a result of leaching (table 3). Sodium and hydrogen ions were stored. The losses are probably the result of overloading of the cation exchange sites by water-soluble calcium mobilized during leaching. This flood of calcium would be expected to remove some ions on the exchange by mass action. Sodium and hydrogen are readily leached. These are thought to have been stored after the heaviest calcium mobilization had occurred. Most ash treatments produced ion levels that were significantly different from the control in this ion-rich soil.

A soil of this classification could be expected to lose some ions as a result of future ashfall. It would not be likely to increase in fertility unless scarce ions such as

Table 3.—Summary of significant differences between the means of net leachate ion concentrations (ppm) summed over 30 weeks of leaching versus ash depth within each soil. Determined by Duncan's MRT or LSD methods at 0.05 significance level[1]

	Ash depth			
Ion	1.9 inches	1.0 inch	0.4 inch	No ash[2]
		Lolo Soil		
[2,5]Ca	–163 a	–88 b	.59 c	[3]–52 c
Cu	.04 a	.12 b	.15 b	–1.09 c
K	57.0 a	70.4 b	71.7 b	93.1 c
Mg	–15.0 a	–11.1 a	–10.6 a	–11.3 a
Na	–97 a	–23 b	14 c	38 d
$H \times 10^{-7}M$	–7.9 a	6.1 b	4.9 c	14.9 d
[4]NO_3	188 ab	317 c	227 b	155 a
		Coram Soil		
[4,5]Ca	1,768 ab	1,882 a	1,733 bc	1,640 c
Cu	.18 a	.21 a	.28 b	–1.08 c
K	137 ab	141 b	156 c	132 a
Mg	209 ab	225 b	190 a	160 c
Na	–150 a	–64 b	–24 c	4.1 d
$H \times 10^{-7}M$[1]	–18.1 a	–6.2 b	–5.8 c	2.0 d
[4]NO_3	1,634 a	1,628 a	1,468 a	1,223 b
		Lubrecht Soil		
[2]Ca	289 a	344 a	421 a	477 c
Cu	.27 a	.3 a	.3 a	–1.06 b
K	141 a	149 a	161 b	170 b
Mg	47.5	53.8	64.9	69.2
Na	–145 a	–38 b	31 b	74 c
$H \times 10^{-7}M$	–15.5 a	–3.1 b	–4.0 c	3.4 d
NO_3	666 a	469 b	519 ab	558 ab

[1] Both methods were used to test data. Results presented are Duncan results unless the two methods disagreed and sizes were unequal, in which case LSD was preferred.

[2] Any two values on the same line for an ion that are not accompanied by the same letter are significantly different, 0.05 significance level.

[3] A positive leachate concentration indicates a net loss of that ion from the soil column, a negative value indicates net storage.

[4] Multiple range tests not valid due to nonhomogeneity of variances, differences indicated are by two-tailed t-test at p = 0.05 level.

[5] Two groups within a line are significantly different at the 0.05 level if they do not share a common letter.

Zn were stored from the ash. Although proof is lacking, there is reason to believe that the ash adds exchange capacity to soils, possibly in the form of small particles that migrate downward under leaching pressure and hold trace elements.

Lubrecht Soil (Typic Eutroboralf, Frigid)

The Lubrecht soil was the most fertile and stored only Na in the 1- and 1.9-inch (2.5- and 5-cm) ash treatments and hydrogen at all ash depths (table 3). Small amounts of Cu were stored from the water by the control soil. Lubrecht soils lost less Ca, Mg, and NO_3 than did the calcium-rich Coram soil. The control lost the most K and Na, suggesting that the ash may add some exchange capacity. The loss of nitrate again suggests the high mobility of this ion and possible low anion storage.

Clearly, many ion interactions are occurring that cannot be explained by our current state of knowledge. The Typic Cryoboralf studied here appeared not to improve significantly in fertility from the application of ash.

Ion Loss and Storage Trends in Soils

The ions that were significantly different in the soil extract were not necessarily the same ions that were significantly different in the soil leachate. Soil extraction and ash leaching produced quite different ion concentrations by ash depth within a soil (tables 3, 4). Calcium, for example, was significantly different among ash depths in the leachate from Lolo soils—except 0.4 inch (1 cm) and the control—but not among the soil extractions after leaching was completed. One explanation may be the difference in extracting power of water and ammonium acetate. The calcium in the Coram leachate showed differences between the 0.4- and 1-inch (1- and 2.5-cm) ash depths, but calcium levels were different in soil extracts from Coram soil for all ash depths and the controls. If the two extractants, water and ammonium acetate, worked with similar extraction energies, then we would expect the Lolo soil to store calcium and the leachate to be little different in calcium content. This is close to what did occur. Differences in calcium concentrations in the leachate were related to ash depth for Lolo soil; more ash produced greater storage. These levels of storage over 30 weeks were low (52 to 163 ppm). The Lolo soil extracts were not able to reflect this low storage level. Some calcium added from ash and water may be complexed in a form not easily extracted by ammonium acetate. In the case of the Coram soil, massive amounts (1,640 to 1,882 ppm) of calcium were lost from the soil in the leachate (table 4), but the ammonium acetate extraction after 30 weeks of leaching removed significantly different amounts of calcium from soil subjected to each ash treatment and the control. Ammonium acetate extraction of the Lubrecht soil removed significantly different levels of calcium from only the 1.9-inch (2.5-cm) ash treated and control soils (table 4).

Potassium was lost from all three soils in nearly equal amounts, yet the ammonium acetate extraction of the three soils produced not only different levels of K among soils, but some significant differences in K levels between treatments within each soil. It must be remembered that the soils used from each area were in truckload quantities. Because complete homogenization of such large volumes of soil is difficult to accomplish,

Table 4.—Summary of significant differences between the means of ammonium acetate extractable ions after 30 weeks of leaching versus ash depth within each soil

Ion	Ash depth			
	1.9 inches	1.0 inch	0.4 inch	0
	µg/g or ppm			
	Lolo Soil			
Ca	596 a	589 a	596 a	601 a
Cu	.64 a	.37 a	.79 a	.59 a
K	104.7 ab	105.1 ab	110.3 a	100.9 b
Mg	108.3 a	101.4 b	102.9 ab	106.2 ab
Na	37.3 a	34.4 ab	60.9 c	47.0 bc
	Coram Soil			
Ca	8,526 a	8,474 b	8,324 c	8,259 d
Cu	1.40 a	1.39 a	.71 b	.76 b
K	275.2 a	273.7 a	27.7 ab	285.8 b
Mg	276.5 a	276.2 a	279.5 ab	281.9 b
Na	54.0 a	43.7 a	46.1 a	40.9 a
	Lubrecht Soil			
Ca	3,520 a	3,470 ab	3,505 ab	3,460 b
Cu	.32 a	.46 a	.45 a	.30 a
K	1,187 a	1,153 b	1,172 c	1,158 bc
Mg	476 a	478 a	491 b	494 b
Na	100.5 a	93.7 b	88.2 c	87.3 c

some lack of homogeneity is still a possibility. Even sodium, which is highly mobile, did not show parallel differences in the leachate and soil extractions.

The levels of ions in the soil leachate from simulated rain water reflect more accurately what is occurring in the soil than does the more artificial ammonium acetate extraction of soils. These results have stimulated further research in this laboratory on the influence of soil extractants on forest soils and the relation of extracts to what is available to trees. The growth response of the seedlings with ash (see following section) except for the 1.9-inch ash treatment suggests that the ions were actually stored. The ammonium acetate extraction is not sensitive enough to show the low ion differences in most cases.

Bioassay of Leached Soils with Lettuce

To determine by short-term bioassay if the soil had improved in productive capability as a result of the ash, Simpson's black-seeded lettuce was grown in the soil tubes after the 30 leaching tests were completed. Results show the greatest dry biomass for lettuce grown on Lubrecht soils (table 5). For all soils except Lubrecht, the control had the lowest biomass. Ion additions from 0.4 and 1 inch (1 and 2.5 cm) of ash increased lettuce biomass by about 100 percent over the lower level for Coram soils, but by only 35 percent for the Lolo soils. Lettuce grown on the Lubrecht soil with 1 inch of ash added weighed the same as lettuce grown on the control soil, while that grown with 0.4 inch of ash actually showed reduced lettuce weight. This suggests a net loss of some essential ions from the Lubrecht soils when 0.4 inch of ash was added, or possible complexing of these ions in the soil in unavailable form. Lubrecht soils did show considerable losses of ions, especially NO_3. Perhaps the ash did not significantly increase the growth of lettuce on Lubrecht soils because they were initially quite fertile. The 0.4- and 1-inch ash additions produced small but statistically insignificant increases in lettuce weight on infertile Lolo soils (table 5).

For all soils, the 1.9-inch (5-cm) ash addition reduced the dry weight of lettuce over that of the 1.0-inch ash treatment, and for the fertile Lubrecht soil and infertile Lolo soil, below the weight achieved on the control soils. This suggests that 1.9 inches of ash may have created poor surface aeration because it was observed that this depth tended to pack with watering, whereas the lighter treatments generally became mixed with the litter as a result of watering. Ash accumulations of over 1.9 inches are not likely to improve fertility of most soils in the immediate future (based on greenhouse tests).

Table 5.—Dry weights of lettuce grown with three soils and three depths of volcanic ash (Mount St. Helens, collected from Moses Lake)

Location	Treatment	No ash control	0.4 inch	1.0 inch	1.9 inches
Coram	X	0.27	0.58	1.22	0.80
per plant	SD	.13	.29	.61	.40
Lolo Pass	X	.33	.49	.41	.13
	SD	.17	.25	.20	.07
Lubrecht	X	2.53	1.94	2.57	.61
	SD	1.26	.97	1.28	.30

The lettuce plants did not show clearly recognizable deficiency or toxicity symptoms according to the key of English and Maynard (1978), but the type of chlorosis suggested possible sulfur deficiency. Nishimoto and others (1977) found that lettuce made its maximum growth with 0.3 ppm P in solution. Based on the P present in the soil leachate, there should have been adequate P present to grow lettuce. Portions of the plants were not analyzed separately, but Berry (1971) found much more Zn in the petioles than in the leaf blades of lettuce. Berry and others (1981) analyzed Grand Rapids lettuce for 20 elements using controlled growth conditions and five different analysts. Comparisons between the nutrient content of two varieties are not warranted, but these are the only comparisons that are possible. In general, the levels of ions in the two varieties of lettuce are similar.

Tree Seedling Growth on Two Soils

Seeds of ponderosa pine, Douglas-fir, western larch, and lodgepole pine were planted in tubes filled with soil and ash applied at the three depths used in the leaching tests.

Results from the second year of growth were similar to those from the first year (data not included). Ponderosa pine seedlings on Lolo soils continued to grow better than on Lubrecht soils (fig. 9). Differences within treatments were not significant, except for the superior growth of ponderosa pine on the Lolo control soils. Douglas-fir on Lolo and Lubrecht soils showed no significant height differences within locations by ash depths or between locations. Lubrecht western larch remained taller than the Lolo western larch during the second

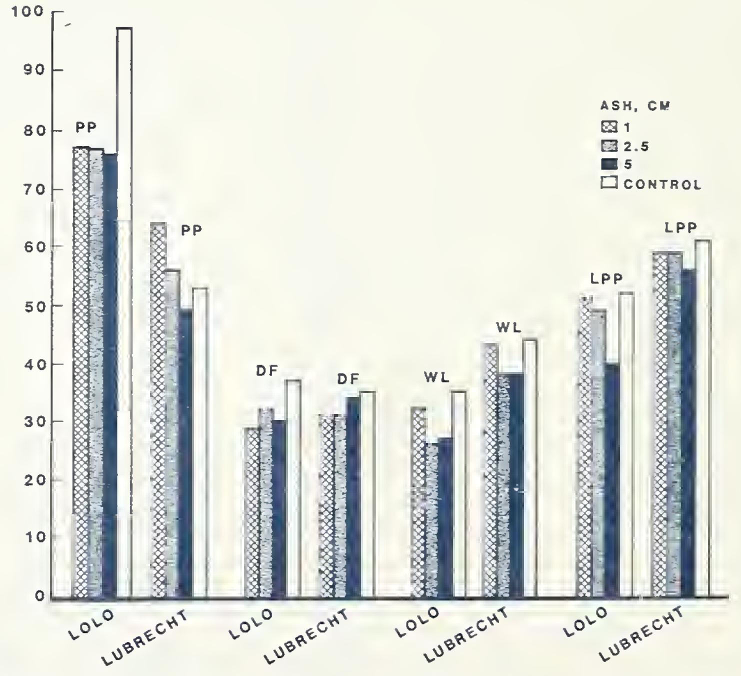

Figure 9.—Mean height of tree seedlings (mm) grown in two soils with three ash depths and control (no ash) for 2 years.

year, but the differences were not significant. Lodgepole pine grew slightly faster on the Lubrecht soil in the second year, compared to the Lolo soil. The 1.9-inch (5-cm) ash treatment continued to suppress growth in most cases (fig. 9).

Survival was best for Douglas-fir on the 1-inch (2.5-cm) ash treatment (90 percent) for the Lolo soil and for the control for western larch (100 percent). All lodgepole pines survived on the control and 0.4-inch (1-cm) ash treatments. Ponderosa pine survived best with the 1- and 1.9-inch (2.5- and 5-cm) ash treatments on the Lolo soil. Survival was poorer on the Lubrecht soils (50 to 100 percent). The 1-inch ash and control generally had good survival for most species.

APPLICATIONS

These results show that the 1 inch (2 cm) of ashfall in western Montana from the 1980 eruption at Mount St. Helens is not expected to significantly affect the fertility of the soils tested in Montana. This short-term study suggests that considerably more ash would have to fall to significantly improve soil fertility levels. The low-nutrient demanding species such as ponderosa pine on nutrient-poor soils may have benefitted slightly from the ashfall, but the results are probably not of sustained significance. If adequate ash fell to improve the chemistry of the poorest soils, adverse physical effects on the soil in respect to aeration and abrasion of vegetation could be expected, although soil water retention might be improved. More than 1.9 inches (5 cm) of ash in a single fallout is slightly detrimental to height growth of young potted tree seedlings, but a similar ash depth would not necessarily adversely affect native vegetation outside the greenhouse.

At present, management practices do not need to be altered to take advantage of the ashfall. Future ashfall of substantially over 1 inch (2.5 cm) may require improved scarification to mix the ash with soil at the time of planting or before seed fall. The impact of ashfall on the entire forest ecosystem cannot be projected from this study.

This study's most significant contribution is to point out areas of uncertainty in our understanding of ion release from ash and storage by different soils. More research on a wider range of soils and for an entire ecosystem is needed to develop a better understanding of nutrient dynamics in ash and soil. Future experiments need to answer specific questions raised by this research. Examples: Why is potassium lost from a soil that can store calcium and apparently has available cation exchange sites? Why do some soils lose nitrate so readily when this ion is usually low in concentration?

CONCLUSIONS

1. Three soils of different initial fertility responded differently to ash additions in the greenhouse in terms of ion storage and release. More extensive study is needed to find the reasons for the responses.
2. Based on the greenhouse results, the 1 inch (2.5 cm) of ashfall that occurred in western Montana in 1980 is not expected to significantly increase the short-term fertility of moderately fertile soils. More time for weathering and incorporation of the ash may show chemical and physical benefits not evident in this study. The inceptisol was too nitrogen deficient to benefit from the ash and could not capture significant amounts of nitrate.
3. Volcanic ash has the ability to remove copper from incoming water and to store this ion. Presumably ash would also remove copper from rainfall.
4. Under greenhouse conditions in the absence of plant uptake, ash does not weather rapidly enough to improve soil fertility for trees after an equivalent of 3 years of leaching as assayed by tree seedling height growth (no data are available on mineralization of the litter). Deeper levels of ash may be detrimental to seedling height growth in the greenhouse.
5. Soils high in calcium and magnesium lost these ions while those low in calcium and magnesium stored these ions. Soil with intermediate calcium levels stored small amounts of calcium.
6. All three soils lost K and NO_3. These losses could influence growth, particularly the K and NO_3. However, less was lost with greater ash depths.
7. Periods of high ion additions in the tap water showed that the exchange sites in the Lolo and Lubrecht soils were not saturated, even though the calculation of base saturation showed them to be saturated. Ammonium acetate solubilizes calcium and magnesium that is not stored on the exchange sites.
8. Under greenhouse conditions, the dry weights of lettuce grown in the three soils with ash added showed improved growth in the short term on the Coram soil, but not on the Lubrecht soil. Ash did not significantly increase growth on the Lolo soil. With 1.9 inches (5 cm) of ash on the soil surface, the growth of lettuce on all three soils was reduced, probably from altered aeration and drainage.
9. No significant height growth differences occurred in seedlings grown on Lolo or Lubrecht soils with ash for ponderosa pine or Douglas-fir. Western larch growth on both soils was extremely poor, but poorest on the nutrient-deficient Lolo soil.
10. At present, management practices do not need to be altered to take advantage of the last ashfall.

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Three western Montana soils of varying fertility and physical characteristics were placed in large tubes, covered by different depths of volcanic ash from Mount St. Helens eruption to test the release of ions from ash and ion storage or loss from the soil. The ion concentration differences between water added and water lost from the soil were used to show net ion storage or loss from the soil. Lettuce and conifer seedlings were grown in the leached soils to estimate the influence of ash on growth. The three soils responded to ion additions differently. Ash improved lettuce growth for only the calcareous soil. Of the four conifers tested, only ponderosa pine seedlings on the poorest soil showed improved growth with ash the first year. Most growth differences were not significant.

KEYWORDS: ash leaching, Mount St. Helens, nutrient storage, soils, volcanic ash

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10529